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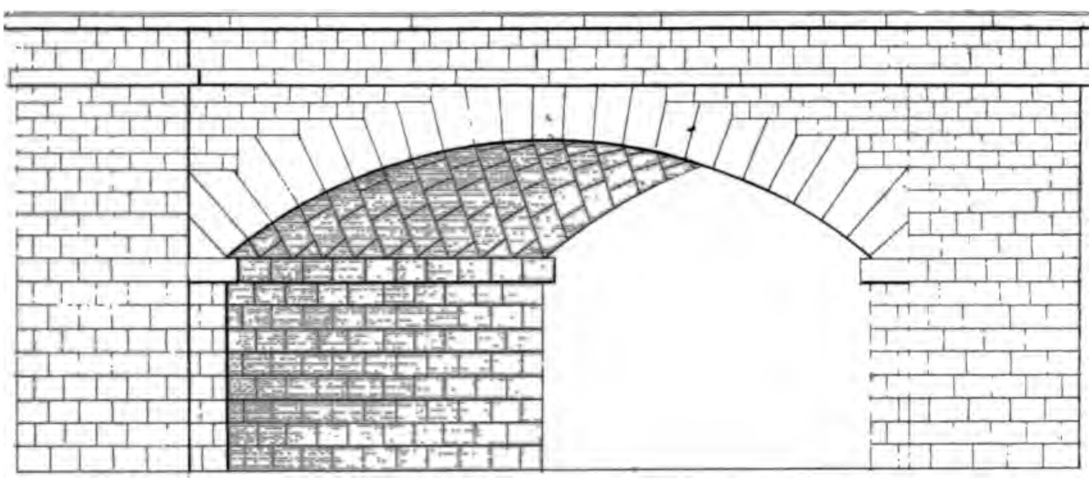
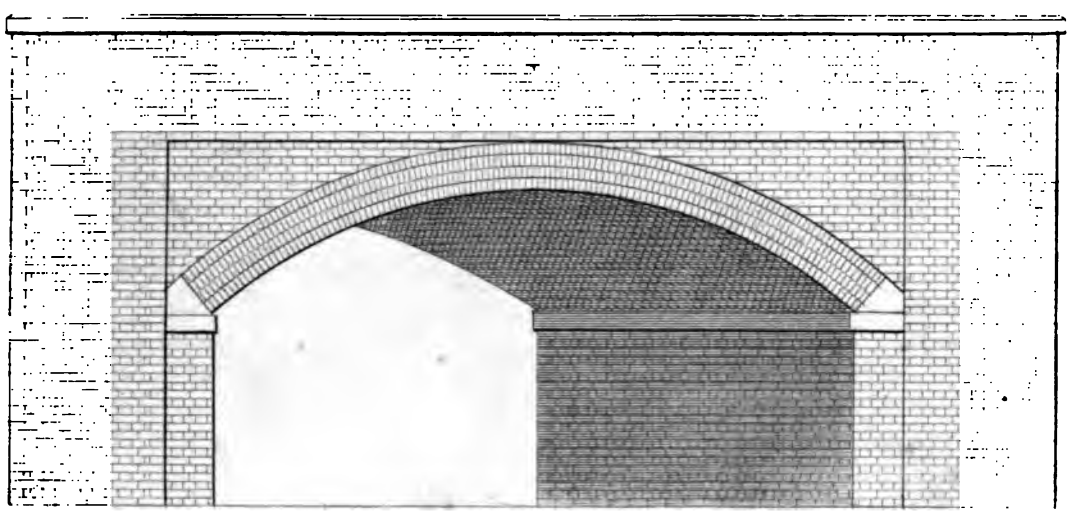
Plate II.

OBLIQUE BRIDGES





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A

PRACTICAL TREATISE

ON THE

CONSTRUCTION

OF

OBLIQUE ARCHES.

BY

JOHN HART, Mason.

SECOND EDITION,
WITH ADDITIONS.

LONDON:
JOHN WEALE, ARCHITECTURAL LIBRARY,
59 HIGH HOLBORN.

MDCCCXXXIX.

TO

ROBERT STEPHENSON, ESQ.,

CIVIL ENGINEER,

THIS TREATISE

ON

OBLIQUE ARCHES,

IS, WITH PERMISSION, RESPECTFULLY DEDICATED,

BY HIS OBEDIENT HUMBLE SERVANT,

JOHN HART.

PREFACE.

In laying the following Treatise before the Public, I flatter myself that I have thrown some light on a subject hitherto apparently but little understood. My principal aim throughout has been to simplify the construction of oblique arches as much as possible, which I trust will be seen upon an examination of the plates and their definitions. I have been more anxious to explain them in language suited to the capacities of the men engaged in the execution of them, than to embellish the work with scientific terms, (which, with many, would require more learning than a knowledge of the work itself,) thus rendering it what it professes to be, a useful reference for practical men:—my own experience, in the superintendance of work and workmen, having placed before me the necessity of adapting the explanations of drawings to the understandings of those engaged in their execution; for much of the value and beauty of a design depends upon the workmen being acquainted with the principles of the construction upon which they are engaged.

If, therefore, this treatise assists in conveying the

draughtman's intentions to the workman's understanding, it will answer the intended purpose;—for I have no doubt that the draughtsman will derive some information, as well as the mason and bricklayer, it having been my principal object, throughout the arrangement of the plates, to make it serviceable to all interested.

Mr. Stephenson, under whom I am engaged on the London and Birmingham Railway, having condescended to allow his name (a name which ranks high in the scientific world) to be prefixed to this work, will, I am aware, procure for it an introduction to a class far different from those I have generally addressed; and I flatter myself that even there it will not be found altogether useless.

The First Edition of this work being sold, I now offer a Second, with additional matter and simplicity, at an additional price.

J. HART.

London, August, 1839.

PLATE I.

THE DRAWING OF A SKEW ARCH, BEING THE SEGMENT OF A CIRCLE ON THE FACE, AND BUILT WITH SPIRAL COURSES, ACCORDING TO THE PRINCIPLES LAID DOWN IN PLATE III.

LAY down the plan *a b c d* to the required angle of the bridge, find the centre *e f*, from *e* perpendicular to *a b*, draw the centre line *e q c*, and from *q* set out the elevation of the arch to the form intended, as *a b* and *c*, numbering each joint as shown, observing always to commence at the first joint on the acute angle of the pier, and at the second on the obtuse, making 2 above *a* horizontal with 1 above *b*; by doing this we have a centre joint which will always be a joint of the keystone on that side the centre nearest the acute pier, this joint will be nearer square than any other in the elevation, which in plate 1 will be 8, and in plate 2, 11; these figures are of importance in finding the bevels, as will be shewn hereafter.

Square down the joints of the intrados to the line *a b* on the plan, as 1 *g*, 2 *h*, 3 *i*, &c.; then parallel to the springing *a d*, draw the straight lines *g g*, *h h*, *i i*, &c. to *b c*. Next through the point *a* perpendicular to *a d*, draw *a j*, *g k*, *h l*, &c. to the point of the springing at *b*, then set the dividers to one of the arch stones, (or rather do not alter them after dividing the arch into the intended number of stones,) begin at *b*, and traverse the lines as at 1' 2' 3' 4', &c. to *j*, then through those intersections draw the spiral line *b m j*, also draw the straight line *b j*, and through the point *j*, perpendicular to *j a*, or parallel to *b c*, draw *j p*, which make equal to *a d*, or *b c*.

Make a mould to the spiral line *b m j*, and with it draw the spiral line *c n p*, which divide into the same number of stones as *b m j*, or as the elevation *a c b*.*

The next thing required is to determine the direction of the bed-joints, or spiral courses, and perhaps the best way is to set them as nearly square from the face of the arch, as the construction will admit of, that is, as the joint on the spiral line *c n p* will allow; therefore, if from the point *b* a line be drawn perpendicular to *b m j*, as *b z*, and if *z* does not fall in one of the divisions on the spiral line *c n p*, it must be drawn to the one it is nearest to, preferring, should it come near the middle of a course, to keep it nearest the springing at *c*.†

This line being drawn, it will determine the number of springers on each of the abutments, all the bed-joints must then be drawn through the divisions on the two spiral lines, that is, from *z* to *p*, and from *b* to 8; but for the courses that intersect the abutment, it is essential that they should be of one size throughout, therefore the springers *b c* and *j p* must be divided into as many equal parts as there are stones between *z* and *c*, as may be seen at *c s t* and *p q r*, &c.

To find the cross-joints, take the mould made from the spiral line *b m j*, and place one point at *s*, and the other at *q*, begin at the division *s* or *q*, and draw a cross-joint through every alter-

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* By dividing the development on the spiral lines, the stones in the elevation of the arch will be equal, but the soffit courses will *not* be parallel. If, on the other hand, it is divided on the straight line *b j*, the soffit courses will be parallel, but the face of the arch stones will *not* be equal.

† (Referring to plate 2.) If the line *m b* is divided at *y*, and A *b* drawn perpendicular to *b y*, it will make the stones at the springing nearer square from the face; but it will throw them more oblique in the centre, therefore no improvement. If the arch is a segment either of a circle or an ellipsis, there is no method better than setting the courses square from the two extreme points and centre of the spiral line.

nate course, place the mould at *t r*, and proceed as before until the whole is completed. This being done, it will present the actual length of each stone on the soffit. These stones, it will be seen, are much longer at the springing of the arch than at the key-stone; this arises from one circumstance only, that is, the soffits of the stones at the springing are considerably more out of square than at the key-stone, as may be seen by figures 6 or 7, yet it must be observed that the bearing surfaces at right-angles to the face are the same throughout, thus proving that a bridge constructed on this principle has no limits, that is, if rusticated as shewn at figure 7. By thus rusticating the soffits, we shall have no acute angles to contend with; not only will this perplexity be overcome, but the soffits of the arch will be very much improved in appearance.

To find the spiral courses on the plan, divide *a d* into the same number of parts as *b c*, and through those divisions as *s u*, begin at *s*, and draw through every alternate division as at 1', 2', 3', 4', &c., proceed in the same way with the others, always bearing in mind to start from the springing with the first cross-joint; every other horizontal division will then be composed of as many parallelograms as there are springing stones on the abutment, each of those forming cross-joints for the spiral courses. The bed-joints are drawn through the intersection of those lines, as at *g a'*, *h b'*, *i c'*, &c.

To find the joints of the soffit or intrados which descend from the face of the arch to the springing, and to the rear face of the arch rising from *k*;—parallel to the springing *a b*, through the intradosal joints as at 2' 1, 3' 2, 4' 3, &c. draw straight pencil lines; then divide the springing *a k*, into as many equal parts as there are springers on the abutment *a d*, as at *d e f*, &c., then from the centre *f* draw *f q'* perpendicular to *c d*, and from *q* draw the straight line *q q'*, and *q'* is the centre for the rear face of the arch; divide *q q'* into the same number of equal parts as *b k*, at *l m n*, &c., set the compasses to the radius of the arch, and

with *l* as a centre begin at *d*, and draw a line through every alternate division, until it intersects the intradosal line of the arch; with *m* as a centre, begin at *e*, and proceed in the same manner, always commencing at the springing line. These lines form the cross-joints of the soffit, and through their intersection with the horizontal ones is the true position for the bed-joints; it will be seen they are slightly curved, and must therefore be drawn by hand, that is, if a true representation of the elevation of the arch be required.

But for the purpose of finding the bevels, it will be sufficient if they are drawn straight; the cross joints in that case may be omitted altogether. These lines not only show the elevation of the arch, but are very important in finding the bevels.

Figures 3, 4, and 5, are the moulds for working the beds of the stones into winding surfaces, and are found in the following manner:—From the centre *q* through the joints 1' 2' 3', draw the three radiating lines *q* 1' *o*, *q* 2' *o*, and *q* 3' *o*. Then parallel to to *q* 1' *o*, draw the lines *s t u*; (it is immaterial where these lines intersect with the radiating ones, for the bevels or angles will always be the same;) these moulds must always be kept parallel to the face of the arch, and the distance between figures 3 and 4 is equal to the square width of one springer; the distance between figures 3 and 5 is equal to two springers. See figures 9 and 10.

The next and most important point is to find the various bevels to work the soffit of the arch-stones from the face or joints, as the case may be.

It is clear from this plate, that there are eight bevels required to work the elevation of the arch from the springing to the keystone, that is, the joint eight is the centre one, therefore we must have eight obtuse and eight acute bevels to work this elevation; it however fortunately happens that the bevels found for half the elevation are sufficient for the whole of the arch, for by finding

the obtuse bevels, we also find the acute, and probably the best and most correct way to find them is as follows:—

Make *k b*, figure 6, equal to *e a*", figure 2, and divide it into eight equal parts, as at *d e f*, &c., perpendicular to *k b*; through those divisions draw the lines *b a*, *d l*, *e m*, &c., then take the distance *d* 1 from the elevation, and set off from *d* to 1, on the line *d l*, figure 6; do the same with *e* 2, *f* 3, *g* 4, &c. to *k* 8; and through these heights from the point *b*, as 1 2 3 4 5 6 7 8, draw the curve line *b* 8, and we have the number of bevels required, that is, eight obtuse and eight acute ones. Bevels may then be set to these lines, and applied to the stones; *a b*, 2 *m*, would be the *bottom bed* of the first course of stones, the *top bed* of the same course would *not* be the same size, for it would be *l* 1, 3 *n*, this would also be the size of the bottom bed of number two course; *but* the *top bed* of number two will be *m* 2, 4 *o*.

For the small quoins, the *bottom bed* of the first course will be *a b*, 1 *l*, and the *top bed* of the same stone will be *l* 1, 2 *m*. It will be seen by these bevels, as well as by the development, that the top bed of every stone is shorter than the bottom, that is, on the soffit only, (for as before observed, all are equal on a square line from the face to the joint.) There is yet another way of finding these bevels, namely, to lay down the lines as has been previously shewn, as *a b*, *l d*, *m e*, *n f*, &c. equal to the width of the bridge; then, instead of taking the heights from the elevation, take them from the line *p* 8, on the development, begin at *p*, and take the distance *p* 1', and transfer from *b* to 1, figure 6; again take the distance 1' 2', and set from 1 to 2, &c. This method of finding the bevels is however far more liable to error than the one previously shewn, as any inaccuracy in the cross-joints, would throw the point at 8 too high or too low, as the case may be. This, however, may be regulated as follows: Draw a right angle, as at *b a c*, figure 13, then take the distance *d d'* on the plan, and set off from *a* to *d*, figure 13; also take the perpendicular distance from the joint 8 on the elevation, to

h on the springing, which transfer from *a* to *e*, figure 13; draw the line *d e*, and with this distance in the compasses, and *b*, figure 6, as a centre, strike an arc across *k s*, which will intersect at the original height, namely at 8; draw the line 8 *b*, and from 8 with the length of the soffit stones, 8 7' 6' 5' 4' transferred, to 8 7 6 5 4, figure 6, we shall then have a curve the same as the one from the first principle. The straight line 8 *b* intersecting at 8, the height found by the previous method, proves that *both* must be correct; for were they not so, obtained as they are by two different methods, derived also from varying principles, it is self-evident they would not come to the same thing; therefore, by using the regulating line 8 *b*, either principle may be relied on as being accurate where they can be put in practice. The former is applicable to every description of arch, the latter only where the arch is of considerable obliquity.

Instead of using bevels, a far preferable method may be adopted; which is, to make *Bed-moulds* of wood, as shewn at figures 7 and 12. It may be seen by referring to this section, that the rustications are formed by taking off the acute points, at 1, 2, 3, 4; and from 5 6 7 they are formed by cutting off part of each; it is also of importance to the uniformity of the elevation, that whatever *width* the chamfer is made at *p*, the same width should be continued round the whole of the intrados; with the moulds thus prepared, the mason has only to lay them on the bed of the stones, and mark round them, he then has the bevel for the soffit of the stone from the face, also the two lines for placing on the parallel straight-edge with the moulds, either figures 4 or 5, as the case may be.

I will next proceed to show the mason the manner in which one of the stones may be worked; for when this is known, there will be no difficulty in working the whole. It is immaterial which bed of the stone lays upwards, for one is just as correct and no more trouble than the other. We will begin with one of the large stones in the first course, as *x x x*, or *z z z*, for these four-

teen stones are all the same in every particular; we will suppose the top bed of the stone to be upwards, as at *i j k u*, figure 9. the mould for this bed is *not a b*, figure 7, but *b c*, (these moulds should be marked across the edges, that they may be always kept in their proper position,) therefore take *b c*, and place on the rough bed of the stone and scribe round the two sides and the soffit, pitch or scapple off the waste stone to these lines, then begin and work a draught along the line 3 *n*, and 3 1, place the parallel straight-edge on the line 3 *n*, then take the mould figure 5 and sink it on the line 1 *l*, until the top edge of this mould is out of winding with the parallel straight-edge. Then draw lines parallel to the soffit, and observe to keep the straight-edge, and also the draughts parallel to these lines. The bed being worked, lay the moulds on again, and cut them in along the side *n* 3, and the soffit 3 1, observing to take off the chamfer at 1, and return it a short distance towards *l*; as the side of the mould 1 *l*, will not be down on the bed, this side cannot be cut to the mould more than an inch or two from the soffit, (this however will depend on the twist of the stone,) a square may be applied on the top of the mould, and a point found at *l*, a line may then be drawn from 1 to *l*, this however is not necessary, for when the mould *a b* is laid on the bottom bed, it will be close to this joint or face whichever it may be, we shall then have found three corners, and may take it out of winding.

Having proceeded thus far, it will be proper to determine the face of the stone, which we will suppose to be 3 *n*, this is *w*, on the elevation, and *v v* on the intrados.

This being the top bed of the stone, and the face forming an obtuse angle with the soffit, we must take the bevel from the line *x* 3 2, this is the bevel *a c*. Had we made the other side of the stone the face, the bevel would have been *e n*; take the bevel *a c*, and apply the stock on the line 1 3, and the blade on the soffit line of the face, observing to mark in the face-mould on the rough stone, to ascertain its true direction; this line being found,

we have only to take the joint or face, whichever it may be, out of winding with it, then cut in the mould along the bottom bed and soffit, turn the stone over, and we shall then have the bottom bed upwards, as shown at figure 10.

Place the mould figure 5, on the line 2 *m*, (this line was found by cutting in the face mould,) gauge the thickness of the soffit at the acute point *b**, then take the parallel straight-edge figure 3, and sink the draught *a b*, until the top is out of winding with the top side of figure 5, and work the bed as before described; take the *Bed-moulds a b*, figure 7, and lay on the bed of the stone ranging the side of the mould *b* 2 with the face 2 *m*, cut in the soffit *b* 2, and the joint *b a*, work the joint, and apply the face-mould, and cut in the soffit, work the soffit, and the stone is finished. In this arch there are thirteen more to work to the same *Bed-moulds* and bevels.

Figure 8 is one of the springers, *a* being the plan, *b* the joint of the acute side, and *b* with *x* placed upon it the joint for the obtuse side, *x* is the mould to which all the arch stones are to be worked; the joints of the springers are of course worked square from the bottom beds; therefore when the mould *b* is applied to one joint, and the mould *b*, with *x* upon it, to the other, each being cut in, the top bed of the springer will have a twist upon it, equal to the mould figure 4; draughts must then be worked parallel to the soffit, as before described for working the arch stones.

If these moulds are sent to the quarry, the stones may be scappled to the proper form, and by so doing, there will be a great saving in the expence of carriage, and in many cases not more

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* If the arch stones are set out by dividing the spiral line, the soffits will require to be worked to a gauge, as there will be a slight difference in the thickness; this would only be at one end of the stone, the other would always be equal to the face-mould.

work for the quarrymen, for it is frequently as easy to form irregular stones to a given mould, as to make them into square blocks. The same rule will hold good with the arch stones, especially if they are worked with *bed-moulds*; for if these moulds, and the face-moulds, are sent with proper instructions, the quarrymen cannot misunderstand them. The moulds in figure 7 may be sent in the following manner: instead of sending the eight moulds separate, send but four, screwing or nailing *a* and *b* together by two strips of wood, as shewn at figure 12: do the same with *c d*, *e f*, and *g h*. Then send with these four moulds the following directions: fourteen stones to the mould *a b*, fourteen to the mould *c d*, fourteen to the mould *e f*, and seven to the mould *g h*. The beds of all these stones to be twisted to the mould, figure 5, *always observing to place yourself against the obtuse face of the stone*, and if the soffit is to the left hand, the mould, figure 5, must be sunk on the side furthest from you, until the top is out of winding with the side nearest to you; (this would be the top bed of the stone as shewn at figure 9); but if, on the contrary, the soffit should be to the right hand, the mould must be sunk on the side nearest you, until it is out of winding with the side furthest from you, as may be seen at figure 10.

If the arch is of considerable skew, these moulds should be made wider, to allow for the face bevels, as it would be useless to send them to the quarry; but as they usually leave an inch on all sides of the stone, this would in most cases be enough; if not, it must be provided against. Then divide these four moulds, by taking off the strips of wood which held them together, and we shall have eight; then get two stones to each of the moulds *a b c d e f*, and one each to *g* and *h*: the beds of all these stones must be twisted to the mould figure 4, as before directed, for the large ones.

Figure 11 is only of use where the *bed-moulds* are *not used*; in that case it is to save the trouble of using two bevels to one stone;

as for instance, in working the stone figure 9, if we had not had the *bed-mould*, we must have used the bevel *e n*, for the joint *i l*; the figures 1 2 3 4 5 6 7, are the lengths of the soffits of all the long stones; a similar gauge may be made to the short quoins.

Figure 12 is two of the *bed-moulds* fastened together.

Figure 14 is a view of half the arch when standing at the centre of one of the abutments, and is found in the following manner: make *a b* equal to *e a''* on the plan, and divide it into the same number of equal parts, as at *d e f*, &c.; from *a* perpendicular to *a b* draw *a e*, and from *b* perpendicular to *a b*, draw *b k*; prolong the lines 21', 32', 43', &c. from the elevation of the arch to 21', 32', 43', &c. of this figure; then through the divisions at *d e f*, &c. draw lines parallel to *b k*, omitting every alternate division; these lines represent the cross-joints, and through their intersection with the horizontal lines, will be the true direction for the bed joints.

Figure 15 is a plan of the springing course, as may be seen at *a'' b*, *e f*. I have drawn in the joints *l m n o*, square from the face, to shew the manner in which they intersect with the skew ones *g h i j*: the only way would be, if wrought square from the face, to find the mould *k*, and work each stone solid to this mould, and when they are fixed, grout the joints with cement: when this is set, sink the mould *x* in a perpendicular position, as at *g h i j*, &c. (the mould *k* may be found as shewn at figure 6 and 7, plate 5). Also see definition to plate 5, respecting the disposition of the joints.

PLATE II.

AN ARCH WITH A SEMI-ELLIPTICAL ELEVATION AND A SEMI-CIRCULAR SECTION, THE BED-JOINTS ON THE FACE BEING AT RIGHT ANGLES TO THE INTRADOSAL LINE.

As far as regards laying down the plan and development, and finding the spiral courses, the definition given for plate 1, will be applicable to all, (plate 6 excepted.) I shall therefore only refer to those parts of this and the following plates, which have not come under notice in the preceding one, which will be the moulds for the twist of the beds, and the soffit bevels: these I shall give in every instance, as the forms of the arches are varied to familiarise the workmen with this part of the operation.

The elevation of the arch is drawn with a trammel, it being impossible to describe an ellipsis with compasses, there being no part of a circle in its composition, a true ellipsis is the section of a cylinder; it must consequently be struck from two centres, continually varying; the intradosal line being drawn, the elevation is set out without paying any respect to the square section, the arch being equally divided on the face. The joints are found according to the principles shewn at figure 4, plate 6, which is by drawing a line from each focus to the joint, bisecting these lines, and setting the joints perpendicular to their intersection. The joints will not tend to the centre of the cylinder *e f*; for when such is the case, the elevation has a very miserable effect.*

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* In this respect I differ from others who have published on the subject; they draw the bed-joints tending to the centre of the cylinder; in that case, the face of the arch stones are of various sizes, and the bed-joints are not perpendicular to the intradosal curve of the elliptical face.

The joints of the intrados are found in the same manner as shewn at plate 1, with this difference only, *there* the cross-joints are drawn from a line passing between the two centres, *here* a mould must be made to the intrados of half the arch, and placed at the divisions *d e f g*, &c. drawing a line through every alternate horizontal course, as at plate 1.

In finding the soffit bevels, it must be observed there are eleven required to work the elevation of the arch, as are shewn by the figures thereon: make *k b*, figure 3, equal to eleven springers, as at *d e f*, &c.; from which raise perpendiculars to *l m n o*, &c.; then take the distance *d* 1, from the springing to the intrados, and transfer it to the line *d* 1, figure 3; set one of the springers forward, from *k* to *o*, take the distance *o* 11, and transfer to *k* 11, figure 3, take the intermediate distances *e* 2, *f* 3, *g* 4, &c. and draw the curve *b* 11; there will then be eleven *bed-moulds*, the number required for working the arch: *a b*, 1 *l* will be the bottom mould for *l'*, in the development, and 1 *l* 2 *m*, the top; the bottom bed of the large stone *m'*, will be *a b* 2 *m*, the top, *l* 1 *n* 3, the bottom bed of *n*,' is *m* 2, *n* 3, the top, *n* 3, 4 *o*. The manner in which these moulds must be applied has been shewn in plate 1.

Figure 4, *a* is the plan of a springer, *b* is one of the joints, and *b* with *x* upon it is the other; when the joint *b* is cut to the mould, and the joint *b x* also cut in, and the top bed worked parallel to the soffit, it will have a twist equal to the mould No. 1 *a*.

The mould No. 1, is found by drawing a line parallel to the springing, to intersect the joint line 1 1. No. 2 is found by drawing a line parallel to the springing, to intersect the radiating joint line 2 2; this mould will work the bottom bed of the first course, as at figure 6. No. 3 will work the top bed of the same course, as at figure 5; this mould is found by drawing a line parallel to 1 1, to intersect 3 3, but in working the long stones, it will be necessary to have the mould which works the beds of the short

quoins placed in the centre of each, as the mould *c* on the line 1 *l* figure 6; the mould *c* is the one for working the top bed of the quoin *l'* on the soffit, and must be applied on the bottom bed of *m'*, or which is the same, 1 *l*, 2 *m*; figure 6 will be twisted to the mould *c*, and the other half to *a* or *b*, therefore the beds of the long stones will be worked to two moulds, and the parallel straight-edge as shewn at figures 5 and 6.

The moulds *a* and *b* are the same, but *c* is found by drawing a line parallel 1, 1, to intersect the joint 2, 2; and *e* by drawing a line parallel to 2, 2, to intersect the joint 3, 3; the others are found in the same way, making the difference between the parallels of the stones, the angle for the moulds to which the beds are worked, the variation of the moulds after working the top bed of the first course, is considerably less: that is, the horizontal stones *x x x*, and *z z z*, are called a course.

Figure 7, is a section through the soffit *p* 10, *p q*, figure 7 being equal to *p q* on the development, and *q r* to *q r*, &c.; the stones *a b c d e*, are the bottom beds of each stone, and *p q r s t* 10, shews the manner in which they may be rusticated at the joints.

The bevel *x*, figure 6, is taken from 1, 2 *p*, the bottom bed of the first stone in the development, and must be applied on the soffit to work the face; the bevel *z* is taken from 3, 4, 5, and would work the face of the quoin on the obtuse side.

The lines *w w* and *y y* is the centre of the arch, on the spiral courses; *o o* is the centre of the arch, and common to both spiral and horizontal courses.

Figure 8; this figure shews the five stones *a b c d e* placed upon each other; it also shews the twist of each stone on the soffit, the line through the centre shewing the twist of the short quoins.

The manner in which the spiral planes are managed in this arch will be shewn at plate 3.

The line *r s* is a line bisecting half the arch; it will shew the number of springers on the line *b k*, without laying down the development; there are five arch stones from the springer to *r s*, therefore the distance *b h* must be divided into five parts, with the dividers thus set traverse along the line from *h* to *k*, and it will determine the number of springers; this will answer the same purpose as laying down the development, and squaring from the two extreme points; for, upon a comparison with each other, the two methods will be found to correspond.

The best way of drawing the segment of an ellipsis is to draw the whole of the intradosal and chord lines, and find the foci, from which all the joints should be drawn, that is, to the segmental portion of the arch. The centres should also be drawn in the same manner, and the ribs set parallel to the face of the arch. This, as an individual arch, is decidedly the best form that can be adopted; but in a continuous line of arches, it will be better to suit the elevation of the skew to the form of the others.

See the elevation of the stone arch in the first plate, or frontispiece, which is the segment of an ellipse on the face.

PLATE III.

AN ARCH WITH A SEMI-CIRCULAR ELEVATION AND SEMI-ELLIPTICAL SECTION ON THE SQUARE.

In this plate I have given a semicircular arch on the face, which of course will be a semi-ellipse on the square section, cut at the conjugate axis. This arch, although a different section from plate 2, is wrought upon the same principle, which I will endeavour to explain in the simplest manner. If we conceive the circle *a b c d*, instead of being a cylinder, to be a thin plate of metal, to be possessed of only sufficient thickness to keep it a perfect plane, and the centre *e* to be fixed on the horizontal axis *g f*, always keeping it at the same angle that *g f* makes with the face of the arch, and at the same time keeping it in a perfectly vertical position, the plate being so fixed at the centre *g* that the horizontal diameter would be *s m*, it would then form a plane with the face of the arch. The motions of this plane must be regulated by the line *m o* being drawn perpendicular to *m n*, the distance from *o* to *p*, being equal to six stones; this regulates the motion of the plane on its own axis, which will be equal to *k l*; during this motion, it is quite clear, it must be propelled along the horizontal axis from *g* to *f*, and as we have supposed the arch to be turned, we will suppose the radiating line 10 *k*, capable of cutting through it during its two motions; we shall then have a true spiral plane, the intrados of which would be the line *i h*, and the extrados the line *t u*.

My opinion is, that a spiral plane cannot be found in any other manner, that would be so well calculated to resist the pres-

sure the arch will have to sustain, which always acts perpendicularly upon the extrados; therefore the gravitating forces should be exerted in the same manner as though the arch were built perfectly square, which is the case with this system, each joint being equal to the joint of a square stone. The face of the arch being perpendicular, it is of importance that the radiating joints should be straight, and that the spiral plane should also be straight at any parallel to the face, and also that the cross-joints should be in the same parallel, both horizontally and vertically.

The method of setting out the elevation, and finding the development, is the same as shewn in the two former plates; the spiral lines on the plan and elevation are not shewn, but I have left exposed the lines from which they are found; and I also wish to shew, that in laying down the lines for working an arch, the task is not a difficult one, as the workman need not trouble himself with more than one spiral line, and that is the line of the development *m q n*; this being found, he can make a mould to it, and draw all the others to the mould. The method must be shewn in which the soffit bevels are found; for when this is once thoroughly understood, the mason will experience no difficulty in the execution of a skew arch of any kind. In the previous examples, the manner of ascertaining the number of springers on the plan and elevation, has been clearly shewn, proving that there will be six springers from *a* to *z*; but if we count the number of joints in the elevation, it will be seen there are eleven bevels wanting to work to the keystone; therefore we must set out five more divisions from 6 to 11, making each of these equal to those on *a z*, which will be 7 8 9 10 11; from these divisions, 1 2 3 4, &c. draw lines to the intrados, at 1' 2' 3' 4', &c. Then draw a line *a b*, figure 2, and make it equal to eleven springers, which divide at 1 2 3, &c. and from these divisions raise the perpendiculars 11', 22', 33', &c., to *b c*, take the distance 1 1' from the elevation, and transfer to 1 1', figure 2; do the same with all the remaining distances, draw in the curve *a c*, and the bevels are found.

These bevels might have been found from the development, the joint 1 being equal to the distance *a* 1', figure 2, and the joint 2, to the distance 1' 2', &c.; the bevels *v w x* for working the beds, are found in the same manner as at plate 1.

If we look along the development of this soffit, it will be apparent that the line *q r*, passes through the cross-joints of two courses of stones, there being five horizontal courses on each side the centre, consequently no key-course; this might have been obviated by making the keystone an even number, instead of an odd one, as may be seen at plate 1 on the elevation; there the horizontal centre passes through the centre of the spiral course, the keystone being even;* the soffit of the keystone, where the number is even, will always be a short one, and where it is odd, a long one. It may be seen, there is a great difference between the lengths of the spiral lines on this development, as at 8 *y*, and *m o*, this variation principally arises from the arch being a semicircle; had it been more oblique, the variation would have been still greater, in proportion to the difference of its obliquity. See plate 5. But whatever the difference in these lines may be, there is none in the horizontal ones; they are all the same length from one elevation to the other, when measured parallel to the horizon, as may be seen at *a a*, *b b*, *c c*, *d d*, &c.; these lines are also equal and parallel to those on the plan; and if the bridge were to be built from horizontal beds, and to be equally divided on the face, these lines represent the different thicknesses of the soffit courses, also the various angles of the quoins,† which will prove that an arch of no greater obliquity than this, would not be calculated to carry any great weight, nor would it, if it sustained its own weight, be very pleasing to the eye.

* The eighth from each springing, and in this plate the eleventh from the springing.

† If an arch is built from horizontal beds the quoins or stones are *weakest* in the summit of the arch; but when built with spiral courses, they are *strongest* in the summit, consequently weakest at the springing.

PLATE IV.

THIS drawing is given, to shew that the regularity in the arrangement of the arch-stones and springers given in the previous plates will be destroyed, where the arch is of stone, and the obliquity but small, as in this example. Here are but seven springers on the abutment, consequently according to plates 1, 2, and 3, there would be but three long stones and a short one in each of the spiral courses; this, according to the proportions of the bridge, would be impracticable, therefore the stones must be made shorter; but this cannot be done without destroying the horizontal arrangement before observable, which will be apparent at *z z z*, the tops of the springers there being of various heights.

This will require more of the workman's attention in the construction, as he will not perhaps have two stones the same length; therefore, for every variation, he will want different bevels; that is, one for the twist of the beds, and one for the soffit of each stone; this, however, will be easily understood, if this plate and its definition be carefully attended to.

If the arch is built of bricks, with stone springers, and ringstones, each may then be made to any size, as may be observed by referring to the development and elevation of the abutment *s r*, no respect being paid to the length of any stone, *but the quoins, which must always be equal to the longest or shortest ringstones;* the joints of the intermediate stones may be wrought square from the face, and the notches cut to receive the bricks, as shewn at 1', 2', 3', 4', by a rod, with the distance of each arris marked upon it. The manner in which these distances are found will be shewn hereafter.

It will not be necessary, where the the arch is of no greater skew than this, and the elevation of no greater rise, to lay down the lines on the plan to find the development, as the face *a s* and *r d* will be nearly straight, therefore draw *b s* perpendicular to *b c*, and make *a s* equal to the length of the intradosal line *a c d*, draw *s r* parallel to *a d*, also equal to *b c* or *d a*, draw *r d*, then divide it and *s a* into the same number of stones as the elevation; from *r*, perpendicular to *r d*, draw *r* 7'', which will prove there must be seven springers on each abutment. This part of the operation must be performed, whether the arch is of brick with ring-stones, or of stone entirely; that is, the number of springers must be ascertained, according to *the principle of working before shewn*, or we cannot find the bevels at figure 3. It will be seen from the elevation, that there are eight bevels required, therefore, make *a* 8, figure 3, equal to eight springers, which divide at 1 2 3 4 5, &c., and from each of these divisions raise the perpendiculars 1 1', 2 2', 3 3', 4 4', &c., divide *a b* figure 2, into seven equal parts, and as there will be eight bevels, set one division forward from *b* to 8, then take 8 8', and transfer to 8 8', figure 3; do the same with all the other heights, and draw the curve *a* 8'; then the divisions above *a* 8', which are equal to *b*, *c*, *d*, *e*, *f*, *g*, *h*, *i*, are the bevels for working the eight joints of the development, as *b*, *c*, *d*, *e*, *f*, *g*, *h*, *i*; these joints, it must be observed, are equal in length to one of the springers. If the longest soffit stones are made equal to one of these, and the short quoins half the length as at *j*, *l*, *n*, *p*, and *w*, *x*, *y*, *z*, the eight divisions at figure 3 must be divided into sixteen equal parts, as *j*, *r*, *k*, *s*, *l*, *t*, &c. In beginning to work the stones, the first bevel required will be for the bottom bed of *j'* in the development; this will be the bevel *j* figure 3, *j* being half the length of a springer, this bevel must be half the length of *a* 1'; but for the top bed of *j'*, *observe*, it will not be the adjoining bevel *r*, but *k*, *r*, being the one for the bottom bed of the short stone *w*, on the other face of the arch; the top bed of *w* will be *s*; the bevel for the short quoin *l*, on the bottom bed is *l*,

and for the top *m*; for the short one *x* the bevels are *t* and *u*; therefore, in working the short stones, it must be observed, that every alternate bevel must be taken for one face, and those omitted in one must be taken for the other. The line from *a* to 7', figure 3, is equal to the line *r* 7" on the development; the mould *a* 1' being equal to *r* 1", and *a* 2, to 2", *a* 3', to *r* 3", and *a* 8', to *r* 8", and if the distance between *r* 8", is not equal to *a* 8' one or the other must be wrong. In the next course, the end of the stone *u* will become the keystone seen at 7", and the point 1" will be at *v*. This is making the stones half the length they would be in case they were wrought to the foregoing principles; *there* the long stones were equal to *two springers*, and in this case they are equal to one, and the short quoins to half a springer. If these stones should be too long, they may be shortened equal to the short quoins, as shewn from the face of the arch *s a*. To make the stones throughout the soffit equal to half a springer; the quoins, which are made equal to three-fourths, will require other bevels, and a mould for the twist of the beds, as at A B C, &c.

To find the soffit bevels of A, from the joint *p q*, parallel to *a d*, draw *p' p*, and from *q*, draw *q' q*, then the bevel for the bottom bed of A is the distance *a p'*, (which has been shewn) and will be three fourths of the distance *a s*, the face of the arch-stone without measuring; because A is three-fourths of one of the seven springers first found; therefore take three-fourths of *a* 1', figure 3, which will be at *r*, and *a r* A is the stone (or mould) for the bottom of A.

But the line *q' q* intersects the face of the second arch stone three fourths of its height from the springing, therefore it will be the same distance along the second division of figure 3, which is the line *s*. (If the perpendiculars *s* and 1' are drawn above the other moulds, they will, as A A, always be sufficient to distinguish one mould from another.) The top bed of B cannot be worked from the same mould, because it does not intersect with the springing *s r*, as may be seen at *m*; therefore, from *m*, parallel

to *r s*, draw *m' m*, which, from the springing, is equal to one fourth of the arch-stone, consequently one fourth of the first horizontal division *a* 1, figure 3, must be taken off, as at *p'*; then perpendicular to *a* 8, draw *p' q'* and 1 *r*,' and parallel to 1' *a*, draw *m' n'*, and B will be the mould required for the top bed of the springer B. The bottom bed of C is carried out in the same manner, as shewn at *k* and *l l* on the development, which will produce the mould C, figure 3. Any other stone is found in the same manner. Take for instance D and E; for the bottom bed of E draw *j j''*, and *h' h''*, parallel to the springing, these two lines will both intersect the face of the sixth arch stone; it is clear, by the way in which these stones are shortened, that the centre division is equal to half an arch-stone, because the length of E is equal to half a springer; therefore the centre division *h' j'*, is equal to the centre half of the sixth division, at figure 3, which will be equal to *v w*; draw *w y* and *v x*, perpendicular to *a* 8, and they will give the mould E. D, or any other stone in the arch, may be found in the same manner, as they will always intersect the face quoins at either one quarter, one half, or three quarters; this is, however, done by making the stones proportionate to the springer. But should the stones not be of equal lengths, they may be worked with quite as little trouble in the following manner:* make a gauge to one of the eight horizontal divisions, at figure 3, (or, which is the same thing, to the square width of a springer, as *b x*,) then measure the thickness of the face-mould on the soffit, which, for the sake of explaining the subject, we will suppose to be thirteen inches, consequently *b x* must be divided into thirteen equal parts, with one part at the end subdivided into eight equal parts, to correspond with the two feet rule, then the bevel of any stone,

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* If a stone arch were built of random courses, it would do away with using bed-moulds, therefore the bevels must be applied as described at plate 1; but an arch thus constructed would not look so well as one built with a brick soffit and stone quoins.

be its length whatever it may, can be found by drawing lines parallel to the springing, as before shewn, and where they intersect with the face of the arch stones, it will only be requisite to measure with the two feet rule that distance from such joint as they are nearest to; then take the rule *b x*, and measure from the same joint on the line *a* 8, figure 3, and square up the points thus found, to pass through the curve line *a* 8', and the required bevels will be ascertained.

If the arch is built of bricks, or of bricks with stone quoins, the lines for each course should be drawn upon the centre before the arch is begun; the most correct way is, to draw the horizontal centre *t* 7", and find its centre *g'*, then *i g' h* is the centre of the spiral courses, therefore take the distance from *t* to *h*, and place on the face of the centre, set off the same distance from 7" to *i*, and draw the line *i*, *g'*, *h*, begin at this line, and set out the courses to each of the springers, that is, from *h* to *r*, and from *i* to *a*; as there are seven courses of stone, and each being equal to four courses of bricks, the springing *s r* must be divided into twenty-eight equal parts, and the courses drawn from the face to intersect each of these divisions. If the mason marks these distances on a rod, he can cut the notches on the top bed of the skew-backs, as shewn at 1' 2' 3' 4', as he proceeds with working them, observing that their direction from the face must be equal to the angle of the bridge.

The moulds, *w x y* and *v*, are for working the beds of the stones, and are found by drawing lines parallel to the springing, to agree with the different lengths; *y* is equal to the longest stones, as at the joint *o*, therefore, from the joint *o*, at *5*, draw *5* 6 parallel to *a d*, which intersects the joint 6, this will be 6 on the elevation. From the joint *k*, draw 7 8, and transfer to 8 on the elevation for the bevel *v*, which will work the quoins A, B, C, &c.; take the distance *a p'*, set off from *a* to *b'* on the elevation, and draw the radiating lines as shewn at plate 1.

PLATE V.

THIS plate is principally given for the purpose of shewing to what extent a skew bridge can be built consistently with perfect safety.* The rise of this arch is one-sixth of the span on the face, but the square section is not more than two and a half the span; the angle of the plan is twenty-five degrees, but by making the rise a sixth of the span, as in this example, will elevate the top bed of the springer to an angle of fifty-five degrees, consequently it increases the angle of the first course of arch-stones to forty, which is obvious at figure 3; it is also evident if this arch had been a semicircle or semi-ellipsis, the first course of arch-stones would have sprung from horizontal beds; the angle would then have been nearly the same as the plan of the bridge, as may be observed by inspecting plates 2, 3, 6, 7; thus proving the necessity of adopting a segment, either of a circle or an ellipsis, where the obliquity of the arch is very great. There is yet another advantage derived from the flattened arch, which is of importance; that is, the lines on the face of the development being but the central portion of a spiral line, produced from a semicircle, are nearly straight; therefore the face and joints of the arch-stones are nearly square from the beds. Compare this with plates 2 and 3. It will also be decidedly the best way to work the joints of the springers square from the face; for, by doing this, the smallest

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* This example, though of great obliquity, is not given as the *greatest* extent to which this principle may be carried; this plate will clearly shew that it may be put in practice on a far greater skew than the one here given.

angles in the skew-backs will be sixty-five degrees, and those are where the *seats or notches* are cut into the springers, parallel from the face of the arch, to form skew-backs for receiving the first course of arch-stones; consequently the acute angles are only the depth of an arch-stone; the remaining part of the joints are square throughout, that is from the horizontal beds to an elevated angle of fifty-five degrees; from this it is evident that the smallest angles in this bridge are the arch stones in the first course, which are forty degrees, though the skew of the bridge on the plan is twenty-five; this, I think, will demonstrate the necessity of setting the joints of the springers square from the face of the abutment, for if the plan of the bridge is fifty degrees or under,* it will be very difficult to keep good the acute arrises of the face joints; in that case, they must either be worked square a short distance from the face, as shewn at plate 7, or worked square through, as in this example; when thus worked, care must be taken to have the stones of such length, that the square joints come together at the bottom of the skew-backs, or they will cross the triangular face of the springers, which would be very unsightly, when standing under the arch.

The bevels *a b c*, are for working the beds of the stones; *b* in this arch will not be required for more than two stones, which are *o o*; in practice these stones may be too short; if so, the quoins, which in the other plates were made equal to two springers, must in this case be made equal to three; for working the twist of the bed of these long quoins, the bevel must be *d*, which is drawn

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* If the plan of a bridge is just forty-five degrees, and the springers are wrought square from the face, the angle formed by the notches, which receive the first course of arch-stones, crossing the square joints, will be forty-five degrees also. But whenever the angle of the plan is *deficient* of forty-five degrees, *that deficiency will always increase* the strength of the skew-backs; therefore the greater the skew of the bridge, the nearer the square joints of the springers are at right-angles to the seat of the arch-stones.

through the third joint from the springing at *a*, because the length of these quoins are equal to the width of three springers; *c* will work the stones that are equal in length to two springers. This arch would look extremely well if constructed with stone springers and quoins, and a brick soffit, in the same manner as shewn by half the plan and development.

Figure 3, shews the bevels or *bed-moulds*, for working the stones; there are twelve, which are found in the same manner as shewn in the four previous plates; the height 12, 12, figure 3, is taken from 12, 12, on the elevation; in this case there are more springers than arch stones on half the elevation; this, however, will not make any difference to the principle upon which they are found, that being always regulated by the number of *bed-joints* between the *springing* and *key-stone*, when counted from the *acute angle* of the abutment.

The two stones *e f*, shew the manner in which the quoins must be worked at the joints, to receive the courses of bricks; the two soffits are laid together, which proves that *f* must be wider than *e*, otherwise the soffits would not be the same length.

(Figures 6 and 7,) 6 is an enlarged mould for working the springers, if they are worked with their joints parallel to the face of the arch. This is the *given* mould, because it is found in setting out the elevation; but if the springing joints are to be worked square from the face of the abutment, the mould will of course be considerably decreased in width, though the height will remain precisely the same; another mould must therefore be found in the following manner: lay down figure 6, which is the mould for the springer, with the face-mould upon it; from the bottom bed *a b*, draw *b b'*, *observing* to make it the same angle as the plan of the bridge; then through the points *d g f c e*, and perpendicular to *a b*, draw *d* 1, *g* 2, *e* 3, &c.; next parallel to *b b'*, through the intersections 1 2 3 4 *a*, draw 1 *d'*, 2 *g'*, 3 *e'*, 4 *f'*,

and *a c'*; then at right angles, to *b b'*, draw *b' a'*, take the heights 1 *d*, 2 *g*, 3 *e*, &c., and transfer to 1' *d'*, 2' *g'*, 3' *e'*, 4' *f'*, &c., draw the lines to these intersections, and it will produce figure 7, the mould required for working the square joints; but the mould for cutting in the skew-backs, (which must be done after the springers are set) is the one used for the arch-stones, and care must be taken to sink it parallel to the face, both in its vertical and horizontal positions.

Plates 1 2 6 7 are right-handed spiral planes *or screws*, and plates 3 4 5 are left-handed ones. The beds of the first four take the same direction as would be formed by the screw of a vice when closing it; and the last three such as would be formed by re-opening one, supposing it closed. This is a point which will require the mason's particular attention, when he begins working the first bed of the arch-stones; as he must be careful on which side of the stone he applies the parallel straight-edge, with the one which is not parallel, or he will twist the bed of the stone to the wrong hand; if this is done, it is rendered useless for the intended purpose, unless there is thickness in the stone equal to double the twist of the bed, so as to admit of its being re-worked.

PLATE VI.

A BRICK ARCH, WITH THE HORIZONTAL AND SPIRAL COURSES INTERSECTING AT A GIVEN DISTANCE FROM THE FACE.

THIS plate is given for the instruction of the bricklayer, and if he makes himself master of the principles here laid down, he will experience but little want of confidence in the execution of any kind of bridges, tunnels, or culverts, that he may meet with, as the rules here given will apply to all.

I have supposed this to be a culvert with a skew end, with the spiral courses intersecting the horizontal ones; *a b c* to be the square section, and 1 2 3 4 5, &c., the horizontal courses of bricks; perpendicular to *c e*, or *a d*, draw *c j*, and divide it into as many courses as there are round the square section *a b c*, as 1' 2' 3' 4' 5', &c.; then parallel to *c d*, or perpendicular to *c j*, draw 1'*k*, 2'*l*, 3'*m*, &c., which prolong to 6 7 8 9, &c.; then form the divisions 1 2 3 4 5, &c.; parallel to *c d*, draw 1 *o*, 2 *p*, 3 *q*, &c. to intersect the skew face *d g a*; parallel to *a j*, draw the lines *o k*, *p l*, *q m*, &c. to the point at *j*, and through the intersections at *k l m n*, &c. draw the spiral line *d s j*, and the straight line *d j*. The line *j d* being much longer than *j c*, it is a proof there must be more courses of bricks; therefore from the point *c*, with *j* as a centre, draw the arc *c t*, take the distance *d t*, and see how many courses it is equal to, which is rather more than five, which being added to 21, makes 26 and a part; but there should be an odd number in order to have a key-brick, therefore divide *j d* into 27 equal parts, as shewn at *u v w x*, &c. then through these divisions, and perpendicular to *j d*, draw in the courses of bricks as far as they are intended to rest on the springing, suppose at *y*; then from the point at *y*, see how they will intersect with

each other ; there are 21 horizontal courses, and 27 spiral ones ; the three's in 21 are seven times, but as the four's in 27 will not intersect, take 28, and set another course above *d* to *i*, take the distance *j i*, and set off from *y* to *z*, draw *y z*, then draw every fourth course, as *a' b' c' d' e' f'*; through these points parallel to the springing *y j* or *d e'*, draw every third course to intersect with every fourth previously drawn, as at *g' h' o'*, &c. the intermediate lines may then be drawn, and this part of the work will be finished.

The next thing is to set out the elevation ; this may be done by a trammel, and when the intradosal line *a b c* is drawn, divide it into as many equal parts as there are courses of bricks on the spiral line *d s j ;* the joints are found in the same manner as shewn at figure 4. But in a brick arch, these joints are not requisite ; it will answer every purpose if the divisions are made on the intrados, from the springing to the joint 1'4, as 1' 2' 3' 4' 5' 6,' &c., which is one past the centre of the arch ; then from 14, on the devolopment, see where it cuts the springing, which is the line *s m'*; take the distance *j m'*, and set on the line *a f* at *d*, draw *d e"* parallel to the springing *a c*, and *d g*, perpendicular to *d e"*; as there are 14 courses in the development that rest on the springing *j m'*, there must be 14 from *g* to *c*, this being divided, as at 1, 2, 3, 4, &c., draw the lines 1' 1, 2' 2, 3' 3, &c., to 14' 14 ; make *a b*, figure 3, equal to the square width of the springing *a e"*, which divide into 14 equal parts, as shewn at 1 2 3 4 &c., to *b* ; and from each of these divisions, perpendicular to *a b*, draw 1' 1, 2' 2, 3' 3, &c., to *a b* ; then take the distance 1' 1, from the elevation, and transfer to 1' 1, figure 3 ; do the same with all the other heights to 14, 14', and *b c* ; then draw in the curve *a c* ;* and *d*, *e*, *f*, *g*, *h*, *i*, &c., are bevels for the bricks on the soffit and face ; the bevel *d*, figure 3, being the one for *d* on the development at the springing *j* ; and the two bevels *c f*, are

* See the manner in which these bevels are found at plate 7.

for the brick *d e*, on the development, &c. If the inner end, or cross-joints of the bricks are cut to the bevel, as shewn on the development, they will have a much better appearance than when they are left square. This need not be done for more than a brick and a half or two bricks from the face, and about two or three high from the springing, as shewn at *d e'*; also those where the horizontal courses intersect with the spiral ones.

If the development is laid down, as above shewn, the bricks may be cut to the proper bevels, previous to being burnt; this plan would save a deal of labour, and make a much better finish, especially if the bricks are of a very hard nature, for then it frequently happens that five or six good ones are broken before one is cut to the intended form; if it is not convenient to lay down the lines full size, they may be laid down at an inch scale to answer every purpose.

It is probable that there are many bricklayers who will consider it too much trouble to observe these rules, I will therefore give one more in accordance with their wishes, whereby they will be able to accomplish the work, without making a drawing for any part of it. This plate, and part of the definition, may be used as a reference.

Suppose the same culvert to be built without laying down the development or elevation; draw the centre forward to *a c*, then at the two points of the springing *a d*, plumb up two straight-edges; take a line or another straight-edge, and place against these two, and draw the face-line *a g d*, upon the centre; (if this line were developed, it would be equal to the face or spiral line *d s j*,) then take a pliant straight-edge, and bend over the centre, keeping the middle of the centre *g*; with the two ends at *d* and *a* draw a line, which will be equal to the straight line *d s j*; this is the one the courses must be set out from; draw the horizontal centre *g h*, and place the centre of a course on this line; then divide the line drawn by the straight-edge into the proper number of courses, and from its centre *g* apply a square,

which make in the following manner: to the middle of the straight-edge, previously bent over the centre, screw a flexible strip of wood at right-angles to the straight side, before it is bent over the centre, this will answer the purpose of a flexible square, which take and press flat upon the centre, observing to keep the two ends at *d a*, and the centre at *g*; with the square thus applied, draw a line from *g* across the centre, which is equal to one drawn at right-angles to the straight line *d s j*, on the development, both methods being square to the two extremes and centre of the spiral line *d s j*: the number of courses from the springing to the joint beyond the centre, is known, will be fourteen; therefore divide the springing into 14 equal parts; place the pliant straight-edge, at *j s d*, and mark on it each course of bricks; then by the calculation previously shewn, we know that there is another course to add to the length, which will make it equal to 28 courses; place one end at *y*, and press it flat on the centre, until the other end touches the springing, as shewn at *z*; draw the line *z y*, and mark each course of bricks on the line *y z*, then with the pliant straight-edge draw every fourth course, as at *u' y*, *n' a'*, *v' b'*, *w' c'*, &c., and draw the horizontal lines *a' g'*, *b' h'*, *c' o'*, &c.; draw the intermediate lines, and it will then be ready for the bricklayer to commence.

Figure 4 is the manner of drawing the joints in plates 2, 6, and 7. Take the distance *d a* or *d b*, in the compasses, and from *c* as a centre, draw the arcs *e f* across the line *a b*; then from any joint in the arch, as at *g*, draw lines to the foci *e f*, and from *g*, draw the arc *i h*, and *from h i*, as centres, draw the arcs at *j*; and *g j* will be the direction of the joint; the same operation must be performed for each.

PLATE VII.

Plate 7 is a plan, elevation, and development of a semi-elliptical arch on the skew-face, every alternate course being darkened, to shew the manner in which the stones are fixed on the centre; each course being laid parallel to the springing, by which means the centre is equally loaded, and the stones have a tendency to bear on the joints and beds, as may be seen by referring to the stones *a b* and *c*; *a* being the first stone to be fixed upon the centre, the next are *b* and *c*; each stone resting on the skew-back of a springer, until they come to *d*; this stone would have an inclination to slip off the bed, if the arch were of considerable obliquity; it may, however, be prevented by letting a plug into the beds of the stones, as shewn at *d* and *e*. After two or three courses are fixed, there will be no danger of this occurrence taking place. This arch is wrought upon the same principle as plate 2; the extrados is found in the same manner as the intrados, with this exception only; instead of drawing the horizontal lines through the intrados, they must be drawn through the extrados; the divisions on the springers are the same.

The bevels or *bed-moulds* of this arch, are a portion of a circle, consequently struck from a centre, which is found in the following manner; it has been shewn by drawing the previous plates, there are ten bevels required to work the elevation of this arch, and as there are but seven springers, set three forward from *a* to *c*, figure 2; bisect *b c*, which is at 5, and also the intradosal line, which will be *e*: make *a b*, figure 3, equal to ten springers; bisect *a b* at *d*, and from *b*, perpendicular to *a b*, draw *b c*, and *d e*; take

the distance *d c*, from the elevation, and transfer to *b c*, figure 3; also make *d e*, equal to *5 e*; then *a e*, and *c*, are three points in the curve, from which raise the perpendiculars *f q*, and *o q*; *q* will then be the centre for striking the curve *a e c*. If *a d* and *d b*, are divided into five equal parts each, they will find the *bed-moulds* required. The soffit of these moulds will always be the segment of a circle, struck from a longer radius than the cylinder which it envelopes: namely, greater than the square section of the arch; therefore, when the length of the radius is ascertained, which can always be correctly done from a drawing on a small scale, the *bed-moulds* can be struck out to the full size, without any further trouble.

The moulds for plates 2 and 6 may be found in the same manner. This principle, however, can only be applied to arches which are a portion of a circle on the square section: it must also be borne in mind, if the arch is a portion of a circle on the face, the radiating section will be the segment of an ellipsis, and must be found, as shewn at plates 1 3 4 and 5.

PLATE VIII.

Whenever the arch is a semi-circle, or a portion of one, on the elevation, the face of the development and cross joints are a portion of a circle also, consequently centres may be readily obtained; from which the whole, or a portion, of the development and joints may be struck: thus, having the elevation *a b c*, and plan *d e f g*, bisect half the elevation *b c* at *h*, draw *h u* perpendicular *a c*. Square to the abutments, draw *l s*, *i g*, and *m p*, produce *g f* to *o*, transfer *u h* from *o* to *g*, from *g*, as a centre, with the distance *g f* strike an arc across *m p* at *r*. From *f g r* find the centre *t*, and strike the curve *f g r*, which is half one face of the development. From *t* make *t y*, parallel and equal one of the abutments on the face; with *y* as a centre, and distance *t f*, strike the curve *g v*, which gives half the development. Parallel to *t g*, from the springing *f*, draw *f B*, which is the proper direction for the spiral courses. These may however be varied a trifle (if required) to accommodate the divisions on the elevation; or it would be better to divide the elevation after the direction of this course is obtained on the development, so as to regulate the number of skew-backs; this also determines the length of the stones in each course. Divide *t y* into the same number of equal parts as there are skew-backs, on *f g*, also divide the face of the development *f r* and *g v*, the same as half the elevation, draw the bed joints parallel *f B*, to the point at *g*; with the radius *t f*, and the divisions on *t y*, as centres, strike in the cross-joints from the springing to the horizontal centre *r v*, which completes half the development.

To find the beds of the stones, or a radiating section from f to B, draw $f n$ perpendicular $f e$; parallel $f e$, from the bottom of the skew-back $f g$, produce the lines to 1, 2, 3, 4, &c.; but as there are ten courses in the elevation and only eight skew-backs, make $f q$ equal the number of stones in half the face of the arch, including the keystone, which produce from $g q$, to 9, 10.

From $f n$, set up the heights obtained from the elevation as described in the previous plates, sketch in the elliptical arc $f z$, which is a section of the arch from the springing to the keystone both included, and contains every bevel requisite for completing the arch, excepting those for the joints and face. The *face* and *joints* of the stones all being a portion of the same circle, one end concave and the other convex, the bevel shewn at A, with a thumb-screw to alter the angle at pleasure, may be made applicable for both face and joints.

Although half the development is here shewn, it is not necessary to draw more than the part $f B q$, as the stones in the other part of the development are but a repetition of those in this part; indeed the darkened course alone contains every variety of stones required, as may be seen by a little attention, it being precisely the same as the section $f z$.

N.B. Arches of great obliquity are much the strongest when constructed with a segmental elevation; whether the segment of a circle or an ellipse, is of little importance, so long as the rise is between a third and sixth of the span of the semi figure. The more oblique the plan of the bridge, the greater is the necessity for keeping the arch flat; and for the following reasons. All semi-arches built with spiral courses are strongest at the summit; because the stones in that position approach nearer to a right angle than in any other; therefore, the more remote from the summit, the more weak the arch will unavoidably be; consequently, as they near the horizon, they decrease in strength and beauty, as they increase in cost and difficulty of construction.

PLATE IX.

THIS plate shews a more simple form of working the arch, as explained at Plate 4; in that example the section is not attached to the plan, therefore the connection between it and the development is not so clearly shewn as in this plate. In this case the darkened course springs from the acute angle of the abutment, at right angles to the face of the development, until it intersects the horizontal centre *p m*. From this course the bevel for any length of stone may be most correctly and expeditiously obtained, whether the position of the stone be above or below it.* Take the stone *A* as an example: from any corner of the stone, as *o*, draw *o, o'*, parallel to the springing, or to the horizontal centre *p, m*, and where *o'* intersects the line *a g*, is one corner of the stone, make *o' x* equal *o h*; the stone is then in the proper situation for being transferred to the section. The curved line of the section *a t d*, is equal to the straight line *a g* on the development, therefore, if a flexible lath be applied on the line *a g*, with one end fixed at *a*, the stone *o' x* may be marked upon it. Remove the other end of the lath from *g* to *d*, and fix that end

* In Plate 8, it is shewn that only a fourth of the development is necessary; but where the stones are of various lengths, it would be better to lay down one half as here shewn, numbering each stone for its respective place; by adopting this method the cross joints may be placed at a proper distance from each other; where this is not attended to, which is too frequently the case, it looks like neglect, on the part of those who have the management, or want of ability, which in its consequences amount to the same thing.

of the lath also, it will then be *nearly* in the form of the curved soffit (the ends being brought nearer together); the mark as taken at *x o'* on the soffit, will then be *t i* on the section, which is the proper place for drawing the joints *i u* and *t v* of the stone *A''*; if necessary a course of stones may be transferred at the same time, and with greater accuracy than by any other means.

The section *a b*, *d c*, is found in the same manner as shewn in the previous plates, namely, from the lines on the elevation, and set up at right angles to the square line *a z*, or parallel to the face; thus, 1', 2', 3', 4', 5', 6', correspond with the lines taken from the springing to the intrados of the arch.

In this example, where the stones are of various lengths, the best method of working the spiral beds is to make a templet to the twist of a foot, two feet, three feet, and four feet, as shewn at 1, 2, 3, 4; then, according to the length of stone to be worked, draw two parallel lines at such a distance apart, as to agree, either with the whole or part of the templet; and upon one line sink the templet, and the other the parallel straightedge, until they are out of winding, either with the whole templet, or with one of the notches corresponding to the length of stone. The figures 1, 2, 3, 4, on the templet, signify that 1, is for a stone a foot long, 2, for one two feet long, &c. It is not necessary that the templets should be sunk at the extreme ends of the bed, but care must be taken that they are parallel to each other, and parallel to the joints also. To work one of the stones, proceed as follows: knowing the length of stone, mark it on the soffit, which produce to *a g* on the darkened course, and from thence to the section, by the flexible lath; after having ascertained the length and bevel of the stone, *sink* the templet and parallel straightedge at the proper distance, as before described, then finish the bed to a straightedge, observing always to apply it parallel to the soffit; supposing the stone in hand to be *A''* on the section, and one bed to be finished with the joints and soffit, *cut in*, as shewn at *i t*, *u v*, set the bevel to the soffit shewn at *A*,

to *o*, *h*, 7, or to 6, 7, *h*, which apply on the bed in the direction *i*, *t*; the draught being finished, reverse the bevel and apply it on the bed from *t*, in the direction of *i*, which finishes the joints, as shewn at 7, *h*, and 6, *o*, take the other ends out of winding, and work the joints; then upon each joint apply the face mould, and cut in the other bed and soffit, (cutting in the face mould gives the proper twist of the other bed and soffit, without the further application of the templet;) which being worked, completes the stone. The same operation is applicable to every stone in the arch.

PLATE X.

THIS Plate shews an arch with a semi-elliptical section on the square; the manner of working is similar to one with a semi-circular section, for in both cases the elevation is a semi-ellipse; but a spiral course taken from one of the acute angles of the abutment to the opposite face of the arch, as represented by Figs. 3 and 4, forms a portion of an ellipse on the soffit. But if the arch is part or the whole of a circle on the square; a section taken in the same direction (as figs. 3 and 4) would form a portion of a circle; as proved at plates 2, 6, and 7.* This circumstance however does not in the least alter the practical operations of the *mason* as described for Plates 2 and 7. (As to the *bricklayer*, he must be informed that the instructions given for Plate 6, are applicable to this form of arch, or to any other form whatever.) The best and most economical way of constructing an arch of this description is to make the bottom bed of the first course parallel to the horizon, in the same manner as for a square arch, with the cross joints parallel to the face, as shewn by the springers *B C D*, and *E*, which are represented in the development by *F G H I*. The top bed or spiral plane is obtained by cutting in *two* face-moulds on *one* joint, and *one* on the other, as shewn at Fig. 1; observing, when working the spiral bed, to apply the straight-edge parallel to the soffit line *p o*; the twist on the top bed will then be equal to the angle *h g i*, which

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* In Plates 2, 6, 7, the sections being a part of a circle, they may be struck from centres, but in this case the ordinates must be taken separately from the elevation, and transferred to the section, as the corresponding figures will testify.

is the difference between the parallelism of the two beds of the second stone on the elevation.

To find the templet for the bottom bed of the first spiral course *N*; from *n* draw *n m*, parallel to the springing, and *k m* includes the second and third courses on the development, therefore make *k'* *m'* on the elevation include the second and third arch stones; parallel to *k'* draw *g h*, and parallel to *m'*, draw *g j'* and *h g j* is the angle to which a templet must be made to apply on the bottom bed, with the parallel straight-edge. Or the two joints may first be worked parallel to each other; then with the templet placed on one of the moulds; and the mould on the other joint taken out of winding with the top edge of the templet; the templet then being removed from the mould, and the two moulds cut or scribed in, gives the proper spiral planes to both beds and soffit. Care must be taken to apply the proper face-moulds, or both beds will not have the true twist;* as an example take the stone *N*; for the face of this stone, the mould used must be *f*, on the elevation; but for the joint of the same stone *n z*, the mould to be used is the fourth from the springing, and represented by *m x* on the development, or *t* on the elevation. Therefore if the two moulds are applied at the same time, and taken out of winding with one of the templets, suitable to either the top or bottom beds, the spiral plane of the other bed is obtained without the application of a second templet: consequently it will only be necessary to make a templet to every alternate joint, that being applicable to the top bed of one course and bottom of the other, the twist on the opposite bed being obtained by the moulds themselves; the parallel width of the stones is shewn at Figs. 3 and 4. After first working the joints, or joint and face, into planes, it will be necessary, in the next

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* Where the arch is a demi-circle, or segment on the face, this precaution is not necessary, the face-moulds being all a portion of the same circle; that is, the face moulds, whether used for the springing or summit of the arch, are the same, providing the arch is equally divided on the face.

place, to apply the bed mould upon the rough bed of the stone, to ascertain the angle of soffit with the joints; this mould, it must be observed, directs the application of the face moulds, which must be both applied at the same time with the templet containing the angle of the spiral bed upon one of the moulds; the top of the templet must be then taken out of winding with the top of the mould placed upon the opposite joint; the templet must then be removed, and the two moulds cut in, (or scribed round) the upper bed may then be wrought to a straight-edge. After the bed of the stone is completed, re-apply the bed mould, and cut in the curved line of soffit. Further, turn the stone over, and work the other bed, as before observed; and upon this bed also apply the bed mould, which likewise gives the curved line along the soffit. By thus applying the *four* moulds, four draughts are obtained on the outline of the soffit; namely, on the bed, by the *two** bed moulds; and upon the joints, or joint and face, by the *two* face moulds. After this it only remains to work the soffit to a straight-edge, observing to apply it parallel to the horizon.

If the springers were wrought with the joints square to the face of the abutment, as shewn at *K L* and *P*, the soffit would have the appearance of *a b c d*; *a, d*, representing the form of the quoins when viewed from under the arch; this method of working would not only be unsightly, but weak. See the quoin *P* on the plan where the projection is greater than the bed, (contrast this springer with *B C*, &c.,) if they are worked thus, a mould must be made to the square section of the arch, instead of using the face-moulds, as shewn at fig. 1.

* Observe the application of the bed moulds in definition to Plate 1.

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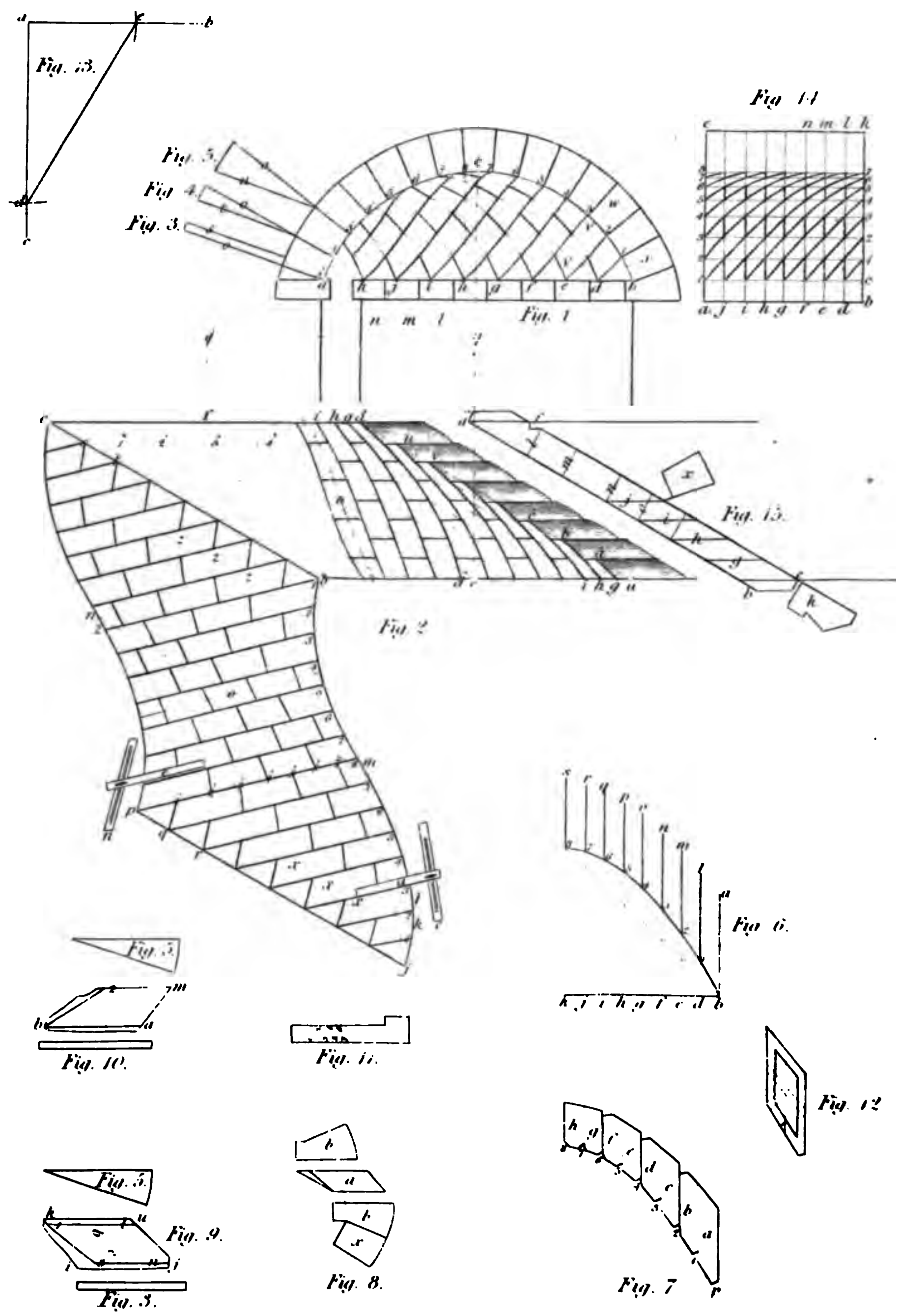

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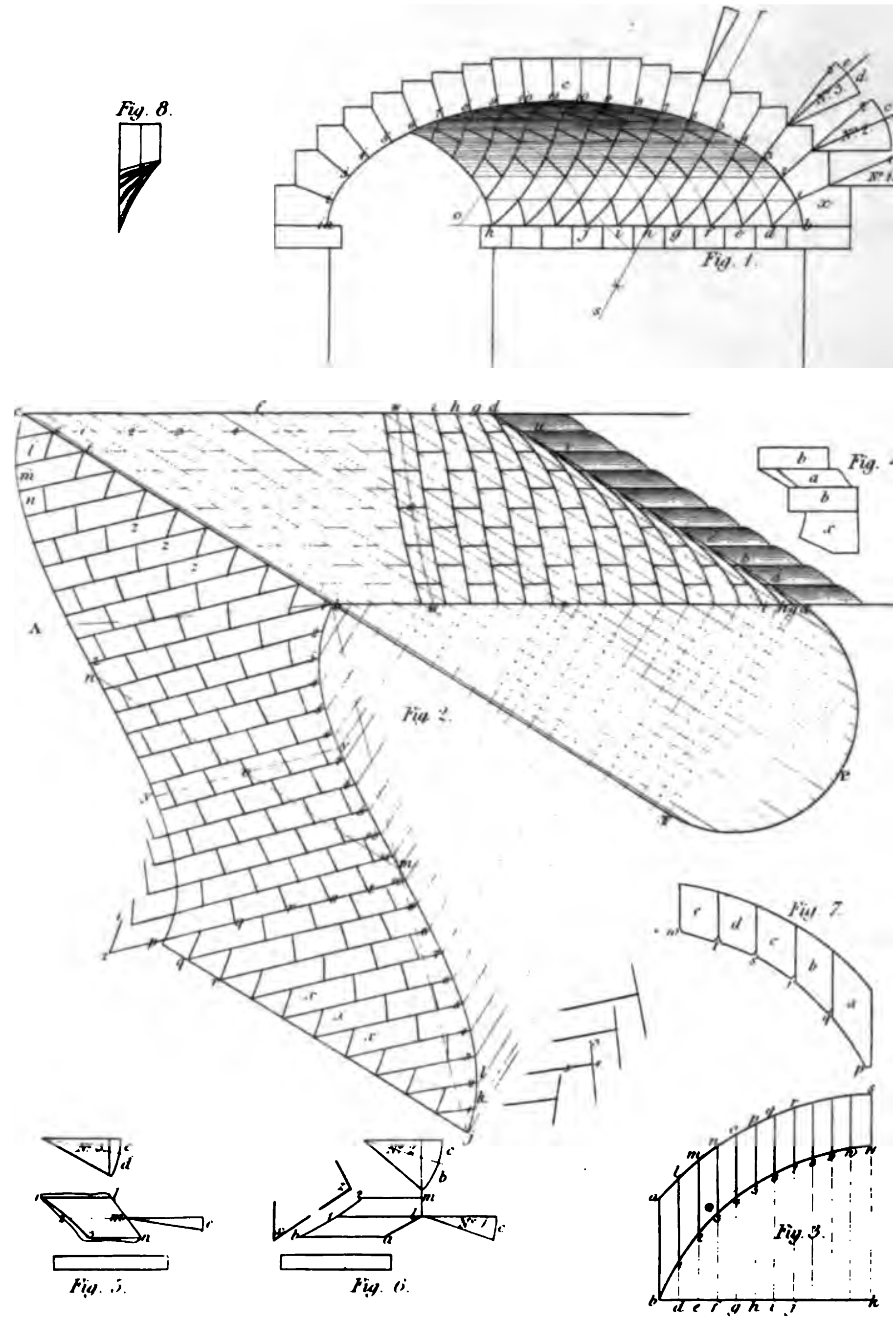

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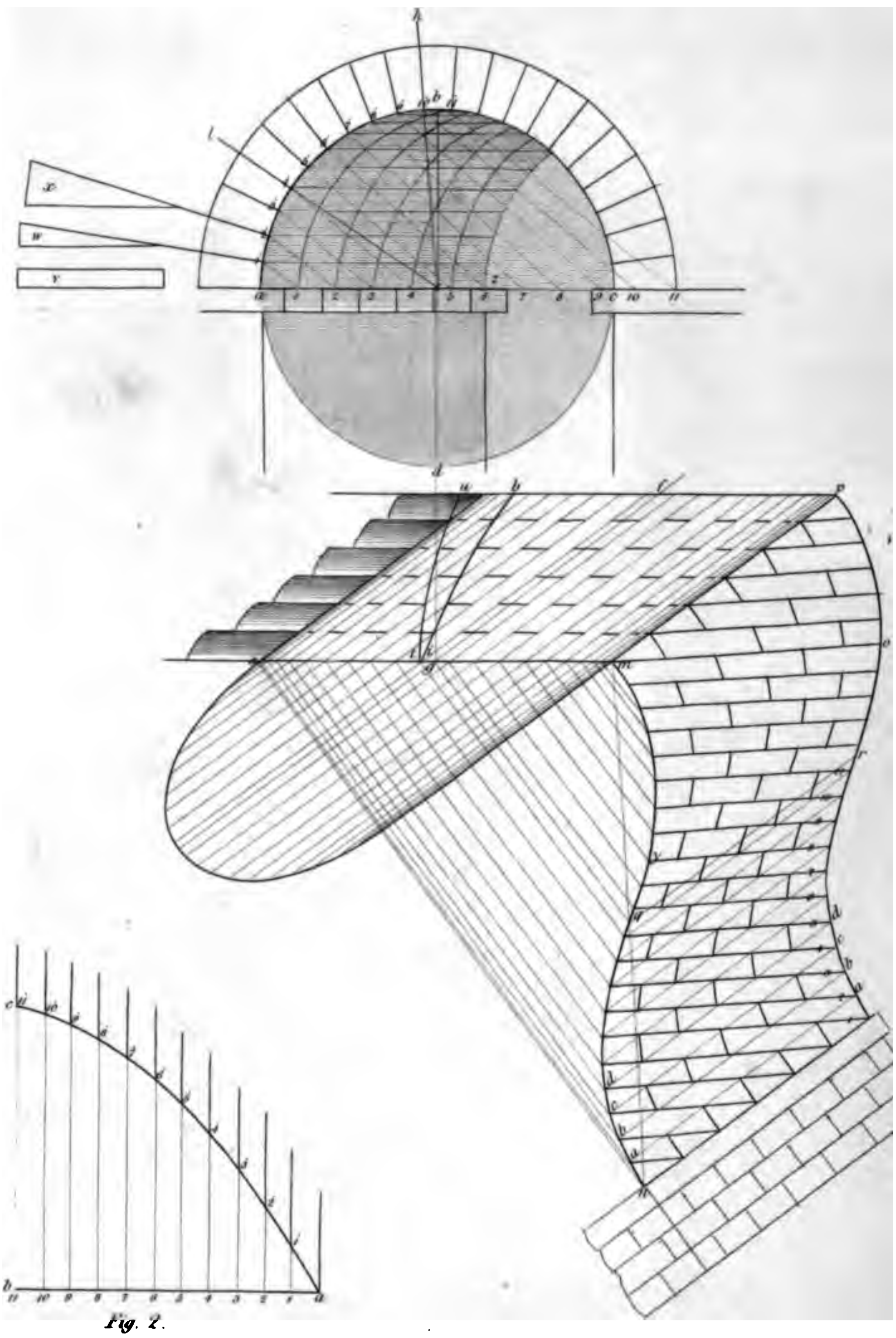

Fig. 2.

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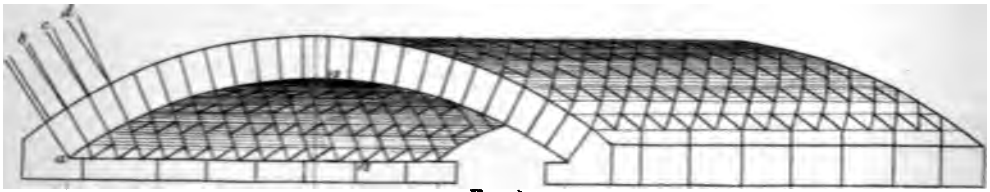

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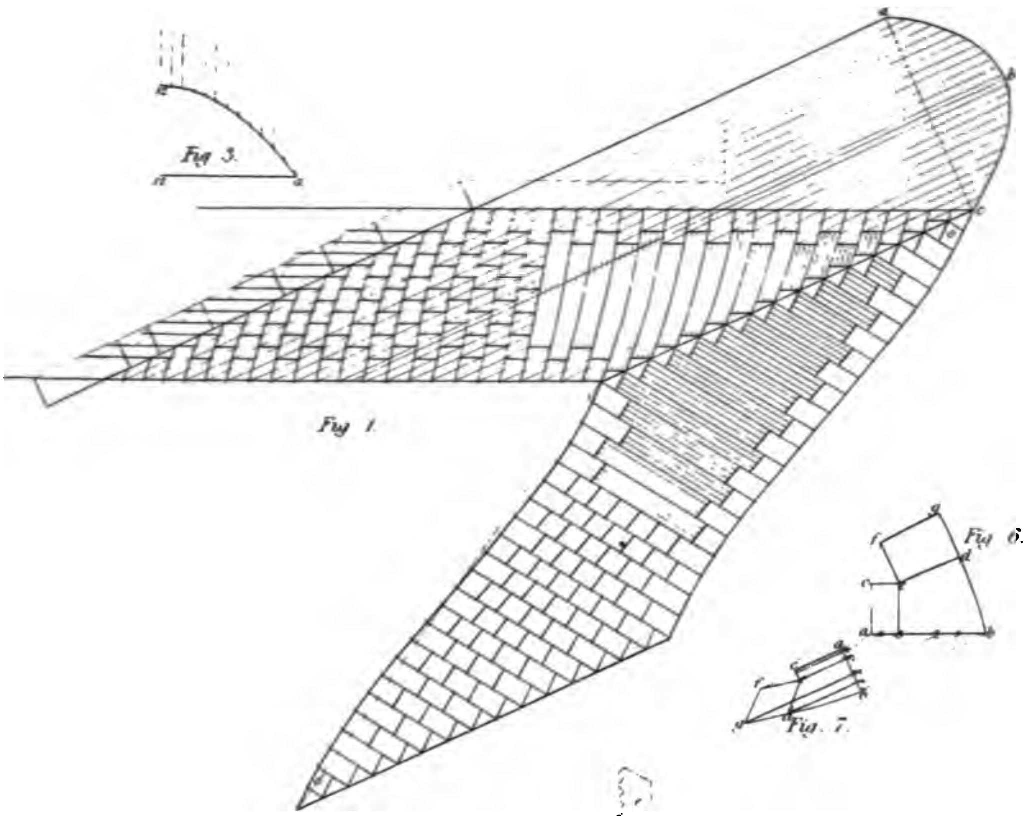

Fig. 3.

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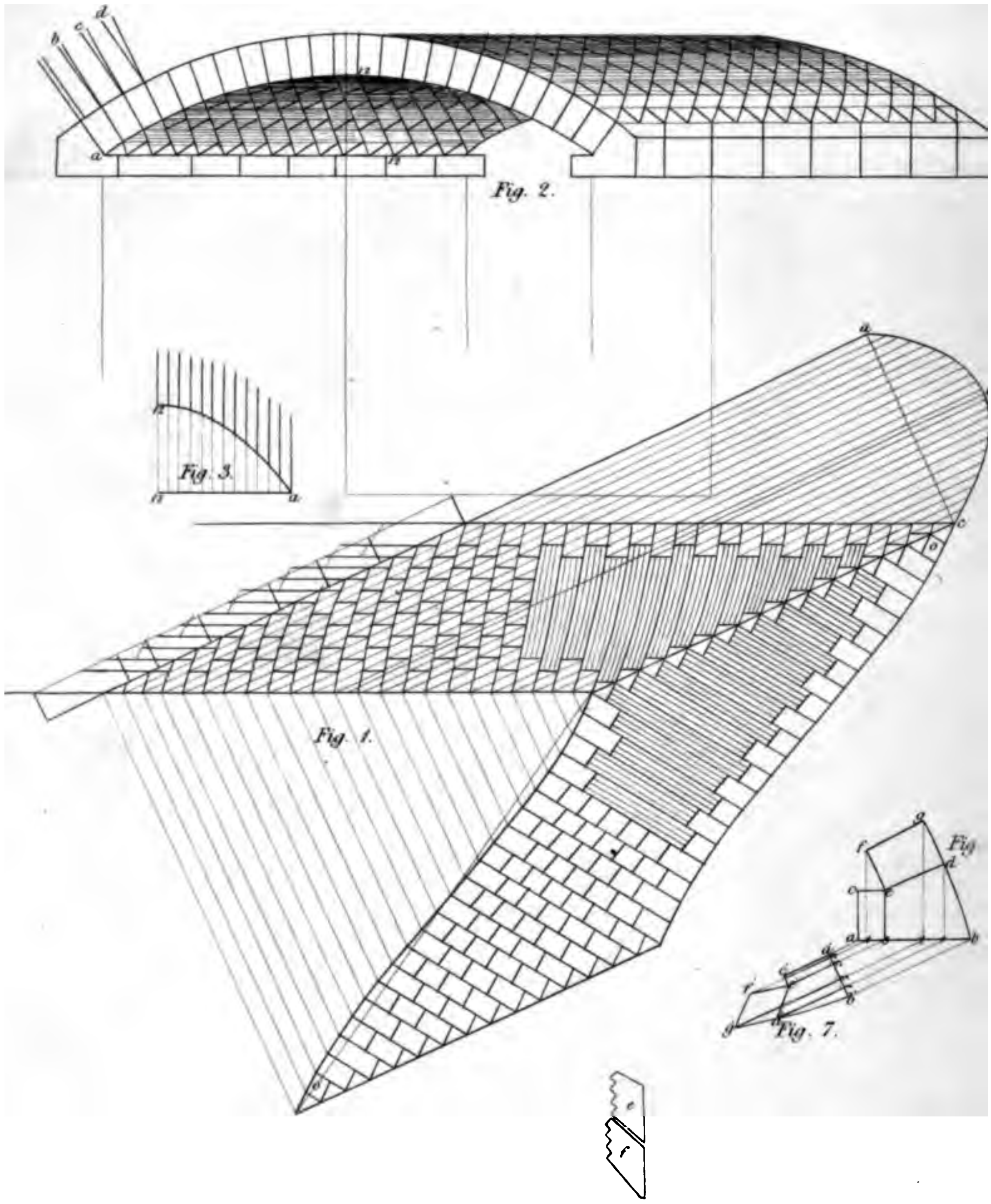

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Plate 6.

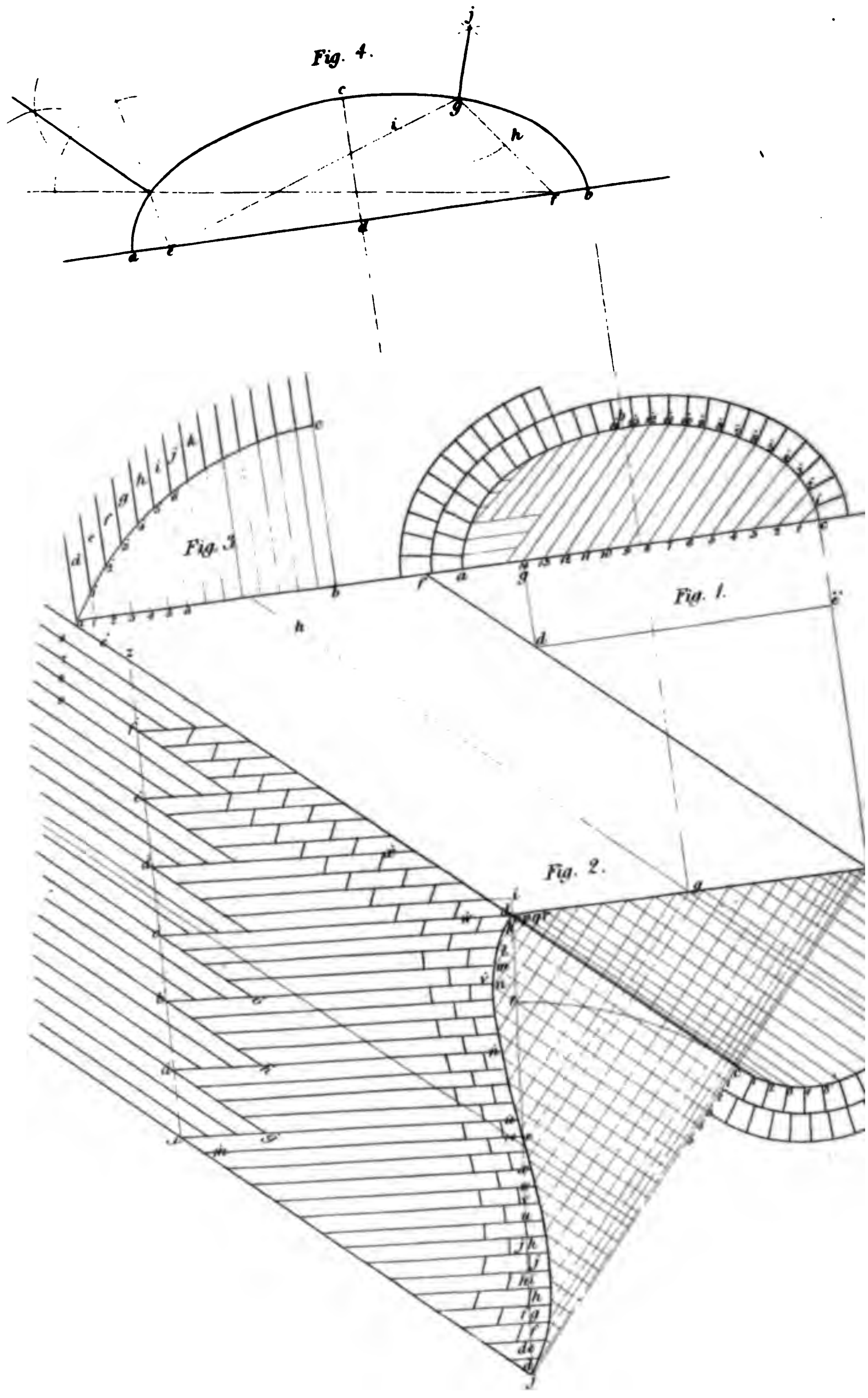

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Plate 7

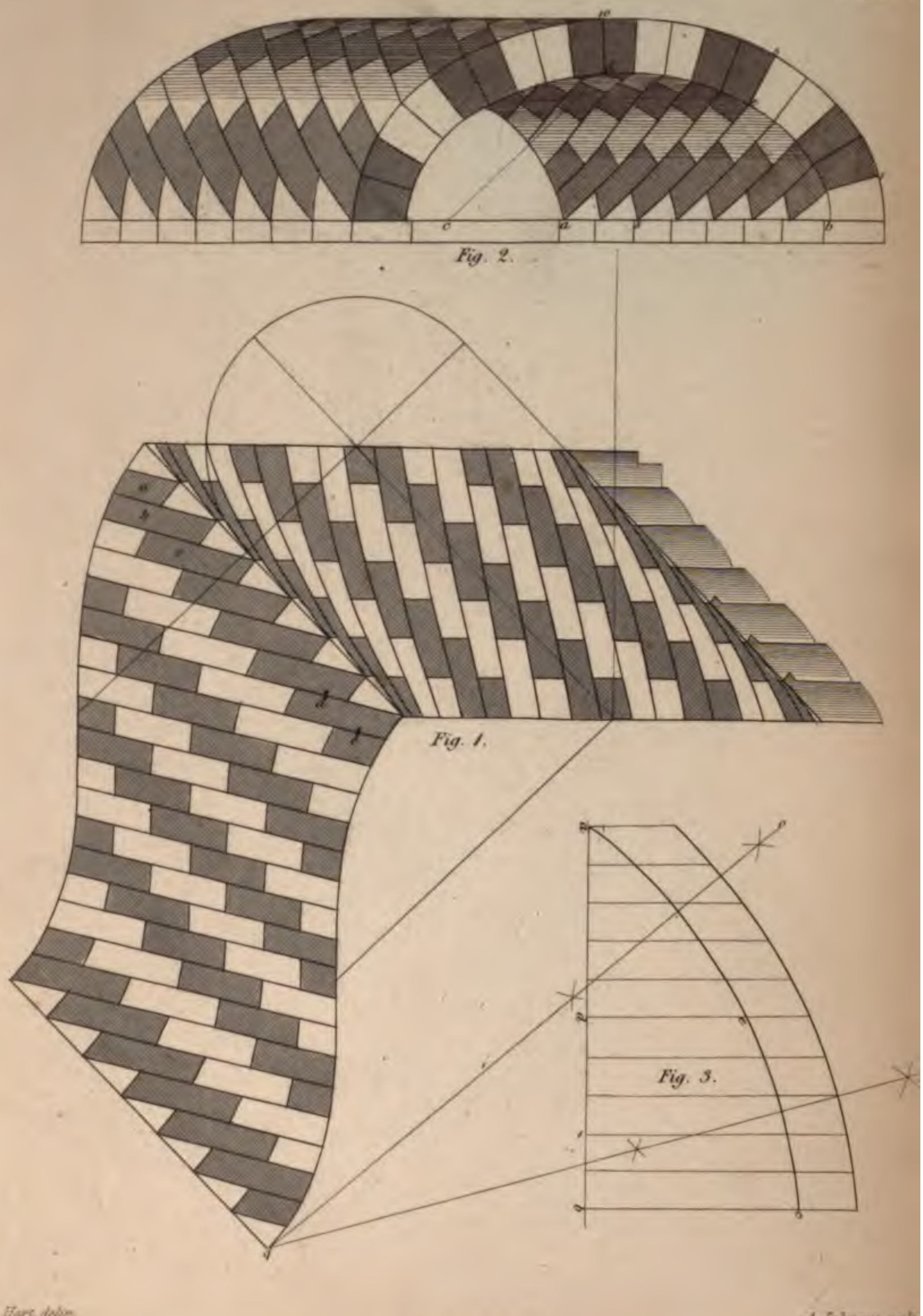

Fig. 2.

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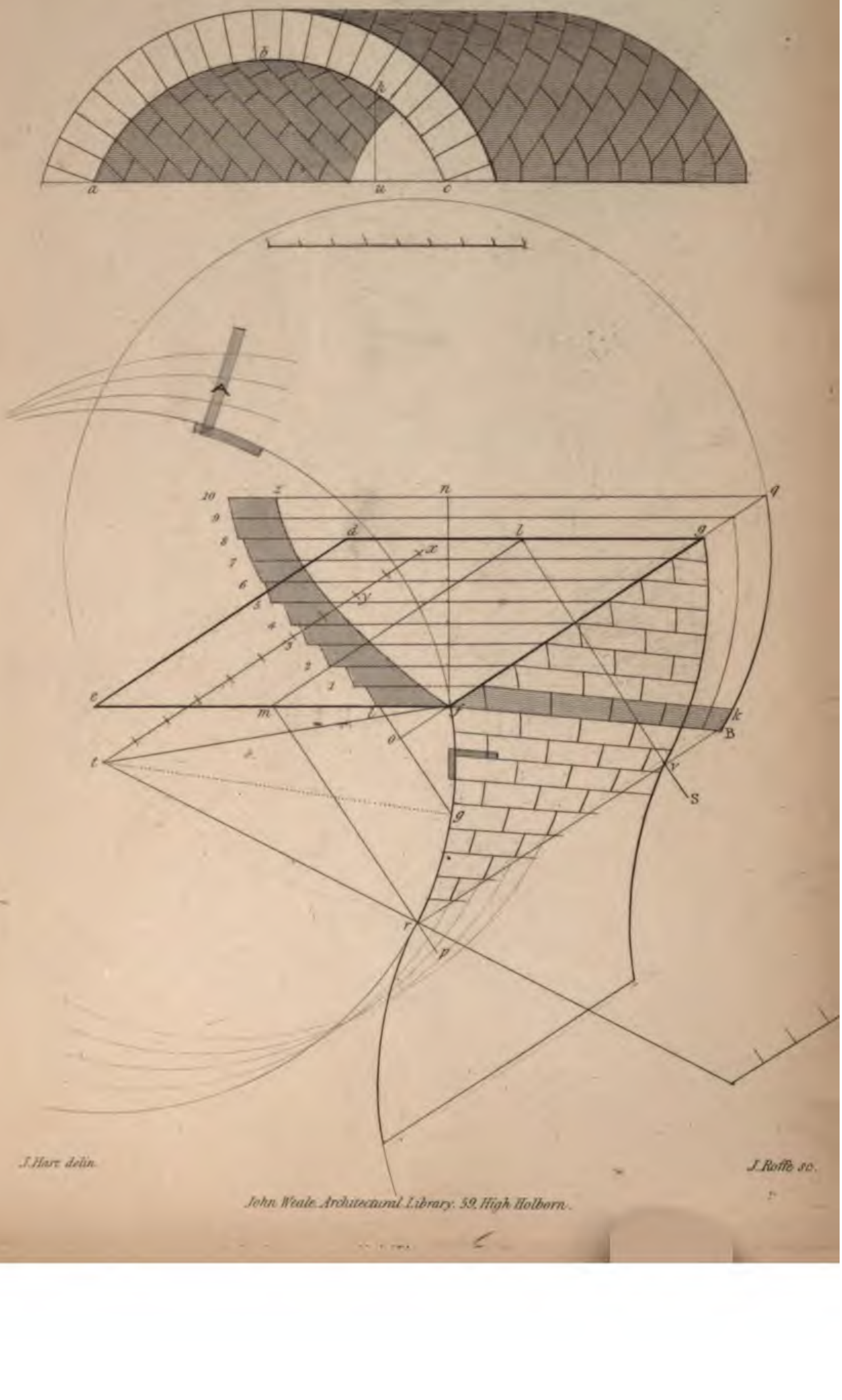

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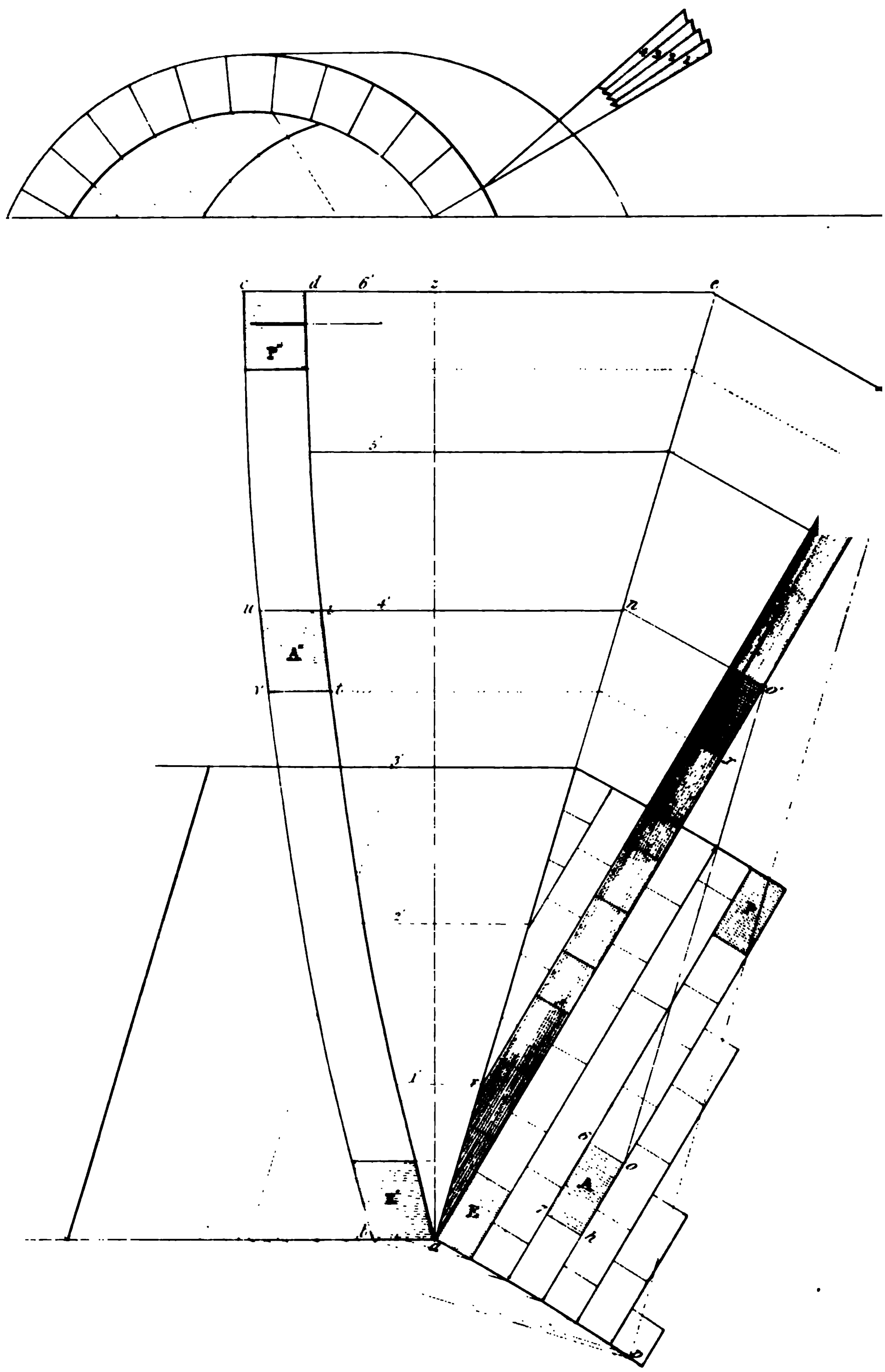

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